HOW INJURY CRITERIA CORRELATE WITH THE INJURY RISK - A STUDY ANALYSING DIFFERENT PARAMETERS WITH RESPECT TO WHIPLASH INJURY

M. Muser[1], W. Hell[2], K.-U. Schmitt[1,3]
[1] Working Group on Accident Mechanics, University and Swiss Federal Institute of Technology (ETH) Zurich, Switzerland
[2] Institute for Vehicle Safety - GDV, Munich, Germany
[3] Institute of Biomedical Engineering, University and Swiss Federal Institute of Technology (ETH) Zurich, Switzerland
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ABSTRACT

This study analyses the significance of different injury criteria by comparing results obtained in sled test experiments to real world accident data.
Standard rear-end sled test conditions (sled velocity 16km/h, 6g trapezoidal pulse) and recent car seats were used in the tests. A BioRID and a RID 2 dummy were utilised. Various parameters including the head and neck acceleration, neck bending moments, the shear forces as well as the head-to-head restraint distance were derived from the tests. The neck injury criteria NIC_{max}, N_{km} and the rebound velocity were calculated.
In a next step, the results from the sled tests were compared with the risk of neck injury as determined from an accident data base. This data base contains several thousand files collected by a major German insurance company and records technical aspects as well as medical outcome (e.g. duration of symptoms). Thus, it was possible to specifically assign the neck injury risk to a certain seat tested in the sled tests.
Finally, the correlation of the injury risk with several of the parameters obtained from the sled tests is presented. It was observed that for the BioRID, the N_{ea} component of the N_{km} correlated best. Although for the NIC_{max} a trend of increasing values for increasing injury risk was observed, the effect was less pronounced than for N_{ea}. Using the RID 2, it was shown that the parameters analysed correlate in a similar fashion, but on different absolute levels. Consequently, it is recommended not to rely on a single criterion but to analyse different criteria in order to assess the protection potential of car seats in rear-end collisions.

INTRODUCTION

To date the biomechanical cause for whiplash injuries is not yet fully understood. Nonetheless various neck injury criteria such as NIC_{max} [Bostrom et al. 1996], the neck displacement criterion NDC [Viano and Davidsson 2001], and N_{km} [Schmitt et al. 2002] have been proposed in order to assess the risk of sustaining such neck injuries from automotive accidents. Especially rear-end collisions are addressed by these criteria. Furthermore, as such criteria are also used to investigate the effectiveness of (seat) systems developed to prevent whiplash injury, they are also important factors in the seat design process.
The development of such criteria is often started from a biomechanical point of view taking into account injury thresholds and reference values, respectively. Different experimental methods, like crash tests, volunteer or cadaver testing, are utilised to support the definition of a criterion and to demonstrate its applicability. Furthermore, statistical studies are conducted to show the relevance of a certain biomechanical measurement value with respect to the injury risk to be determined by the criterion in question. Accident data bases are used for this purpose that, if up-to-date, represent the current vehicle fleet. Difficulties arise when new designs, for example intended to prevent whiplash injury, are introduced. As shortly after the introduction only small numbers of cases are collected in data bases a sound statistical analysis addressing the correlation between injury criteria and the real world injury risk is hardly possible for such new designs. Hence the correlation between established injury criteria and new designs has to be re-evaluated retrospectively, possibly leading to changes in the definition of these criteria or the development of new ones.
Further complications are implied in the choice of the anthropomorphic test devices (dummies) used for definition of an injury criterion. It is generally accepted that the dummy design can strongly influence the outcome of an experiment. Likewise, the test protocol used can result in different values for injury criteria, making a comparison between different test series difficult or impossible.

Concerning whiplash injuries, this dependency on the dummy type is particularly obvious, as there are several dummies used in crash experiments mimicking rear-end collisions. Besides the Hybrid III (with and without TRID neck), the BioRID as well as the RID 2 are in use. Whereas several studies have shown that for rear-end impacts the results obtained with a Hybrid III are unsatisfactory to assess the risk of whiplash injury [Hell et al. 1999, Langwieder et al. 2000], recent studies indicate that both other dummies seem capable of this task. However, rear-end sled tests performed with the BioRID and the RID 2 yielded different values for the same injury criterion [Zellmer et al. 2002]. Furthermore, the choice of different calculation methods and threshold values, respectively, has to be considered when operating different dummy types [e.g. Muser et al. 2002]. Therefore it is important to know the correlation of an injury criterion and its associated real world injury risk for each dummy in question.

This study aims at investigating such correlations focusing on neck injuries sustained in automotive rear-end collisions. Analysing the results from sled tests performed with different vehicle seats and evaluating an accident data base, it was possible to assess the injury risk in relation to according neck injury criteria. Additionally, differences between the BioRID and the RID 2 are presented.

MATERIAL AND METHODS

The correlation of neck injury criteria and the real world injury risk was assessed on the basis of results from sled test experiments and an accident data base. The sled tests were performed with various seats from current car models. Two different anthropomorphic test devices were used: a BioRID dummy and a RID 2 dummy. After evaluating the sled tests, the results obtained were correlated with the risk to sustain whiplash injury as determined from a accident data base. The correlation was evaluated graphically by plotting linear trend lines for each dummy type and for each parameter analysed.

Sled tests

The sled tests were performed according to the "Test Procedure for the Evaluation of the Injury Risk to the Cervical Spine in Low Speed Rear-end Impacts", proposed for the ISO/TC22 N 2071 and ISO/TC22/ SC10, respectively [Muser et al. 1999] using a BioRID II and a RID 2 dummy as anthropomorphic test devices (ATD). The seat was mounted on the sled and recliner and seat base adjustments were made to ensure a 25°± 2° torso line and a 12°± 1° seat ramp using a H-point machine according to SAE J 826. The dummies were positioned in the seat according to the procedures described in ECE R 94. The ATDs were instrumented with accelerometers located at the head, lower neck, chest and pelvis. On the upper neck (C1 level) forces in x and z direction were recorded and the bending moment around the y axis was measured. The crash pulse used in the tests was a trapezoidal shaped pulse with an sled deceleration level of 6 ± 1g and with rise and fall times of 10 - 20 ms. The resulting delta-v of the sled was 16 ± 1 km/h. As for the evaluation, NIC_{max} [Bostrom et al. 1996], N_{km} [Schmitt et al. 2002] were calculated using the following equations:

$$NIC(t) = 0.2 \cdot a_{rel}(t) + (v_{rel}(t))^2 \quad (1)$$

$$N_{km}(t) = \frac{F_x(t)}{F_{int}} + \frac{M_y(t)}{M_{int}} \quad (2)$$

where a_{rel} and v_{rel} denote for the relative acceleration and velocity of the highest (occipital condyles) and lowest (C7/T1) point of the cervical spine, respectively. NIC_{max} is the maximum value of the NIC(t) curve during the retraction phase. Currently the critical limit for the NIC_{max} is $15m^2/s^2$ [Bostrom et al. 1996].

$F_x(t)$ and $M_y(t)$ are the shear force and the flexion/ extension bending moment, respectively. Both values are obtained from the load cell positioned at the upper neck. F_{int} and M_{int} represent critical intercept values used for normalisation. The threshold value currently proposed is 1.0 for all possible N_{km} load cases [Schmitt et al. 2002].

Additionally, the rebound velocities [Muser et al. 2000] of the head and the first thoracic vertebra were determined.

Data base

The data base established by the GDV Institute of Vehicle Safety, Munich, was used as a basis to determine the neck injury risk in real world accidents. This data base registers collisions reported to a large German insurance company and was evaluated with respect to rear-end accidents that occurred in the years 2000 and 2001 (N=approx. 300.000). To qualify for inclusion in this study a case had to fulfil the following requirements:

-) collision type: rear-end collision

-) according sled test data must be available for comparison

-) minimum of 100 cases per car model

With the data recorded it was possible to differ between cases without Cervical Spine Disorders (CSD), with CSD for up to 6 weeks and with CSD lasting longer than 6 weeks.

RESULTS

Evaluating the data base for the years 2000 and 2001, five different car models were identified which qualified for entry in this study. Different car models were separated and the according CSD incidence rate was compared. Table 1 summarises the results obtained from the data base.

While for all those five seats sled tests results were available for the BioRID, results for the RID 2 only included seats A, B, and E. Generally the NIC_{max} values correlated well with the injury risk indicating a trend line with positive slope for both dummy types. The according diagrams are presented in the Appendix.

With respect to the N_{km} values, the strongest trend was observed for the N_{ea} load case. However, this load case was detected for the BioRID only. The N_{ea} was not at all observed for the RID. Other N_{km} load cases did show negative trend lines.

As for the head-to-head restraint distance, both dummies were positioned identically. Thus for both dummies the same results were obtained. An unexpected trend with a declining trend line was observed.

Concerning the dummy used, it was found that the trend lines for the shear forces in both directions were on a higher level for the RID 2 than for the BioRID. However, it has to be noted that for anterior shear forces the results obtained with the RID 2 showed a remarkable spread. The evaluation of NIC_{max} resulted in a slightly higher level for the BioRID. In contrast the trend lines for the RID 2 were higher for the N_{km}.

In summary, the comparison between the BioRID and the RID 2 shows that the according criteria were on different absolute levels but exhibited consistent trends throughout this study, i.e. only minor differences in the slopes of the trend lines were found when comparing different duration of CSD symptoms.

DISCUSSION

It was found that, although NIC_{max} showed in all cases a positive correlation between injury risk and values measured in our tests, the slope of the associated trend line was, however, relatively flat, which means that inaccuracies in the testing procedure may severely compromise the value of NICmax as a predictor of real-world performance.

N_{km} shows a good correlation only in its N_{ea} component, but this component exhibited the strongest slope of all parameters analysed, making it useful as a predictor.

Apart from the small number of seats and corresponding real-world data sets, a severe limitation to this study is probably to be found in the accident data base. The advantage of having a (very) large number of cases is (as with most data bases) associated with the disadvantage of having only limited information on the individual cases themselves. Repair cost is known not to correlate well with physical collision parameters such as delta-v and mean/peak car accelerations, and, on the other hand, "duration of symptoms" is biased by individual judgement and may, in communication with insurance companies, also be subject to aggravation. Furthermore, the association of the duration of symptoms to the severity of the injury itself can be problematic, because, on the one hand, symptoms which in the first time after an accident may have been judged as 'minor' (i.e. QTF 1) may persevere for a long time, while, on the other hand, it is well-

Table 1.

Results from the data base evaluation.

Car model	rear-end collisons registered	CSD claims (total)	CSD risk	number of CSD claims with sick leave time	
				up to 6 weeks	more than 6 weeks
A	139	34	0.245	24	10
B	201	42	0.214	35	8
C	122	22	0.180	18	4
D	204	83	0.407	63	20
E	934	341	0.365	249	92

known that severe injuries (e.g. vertebral fractures) sustained in accidents of a severity incomparably higher than those discussed here, often heal without any long-term sequelae at all.

With respect to the data obtained from the sled tests, it must be noted that the seats included in this study did by no means exhibit extreme values for NIC_{max} and N_{km}. These seats, consequently, would be rated 'average' based on the test results, which is also reflected in the real-world data where injury risk figures between approximately 0.2 and 0.4 were recorded. Including 'extreme', i.e. 'good' and 'bad' seats as concluded from tests in comparison to what is found in the data base, could be a way of obtaining more significant results.

CONCLUSIONS

Correlating neck injury criteria as measured in e.g. sled tests to real-world injury risk figures can be a viable way to arrive, ultimately, at methods to predict the protection potential of a seat system. In particular, N_{ea}, when applied with a BioRID dummy, shows promising trends for this purpose. Inclusion of data from 2002 (not yet available) could enhance the significance of this study.

In view of the severe limitations of this study, mainly the small number of cases, we must, however, conclude that it is far too early to include or exclude some of the existing criteria from further consideration.

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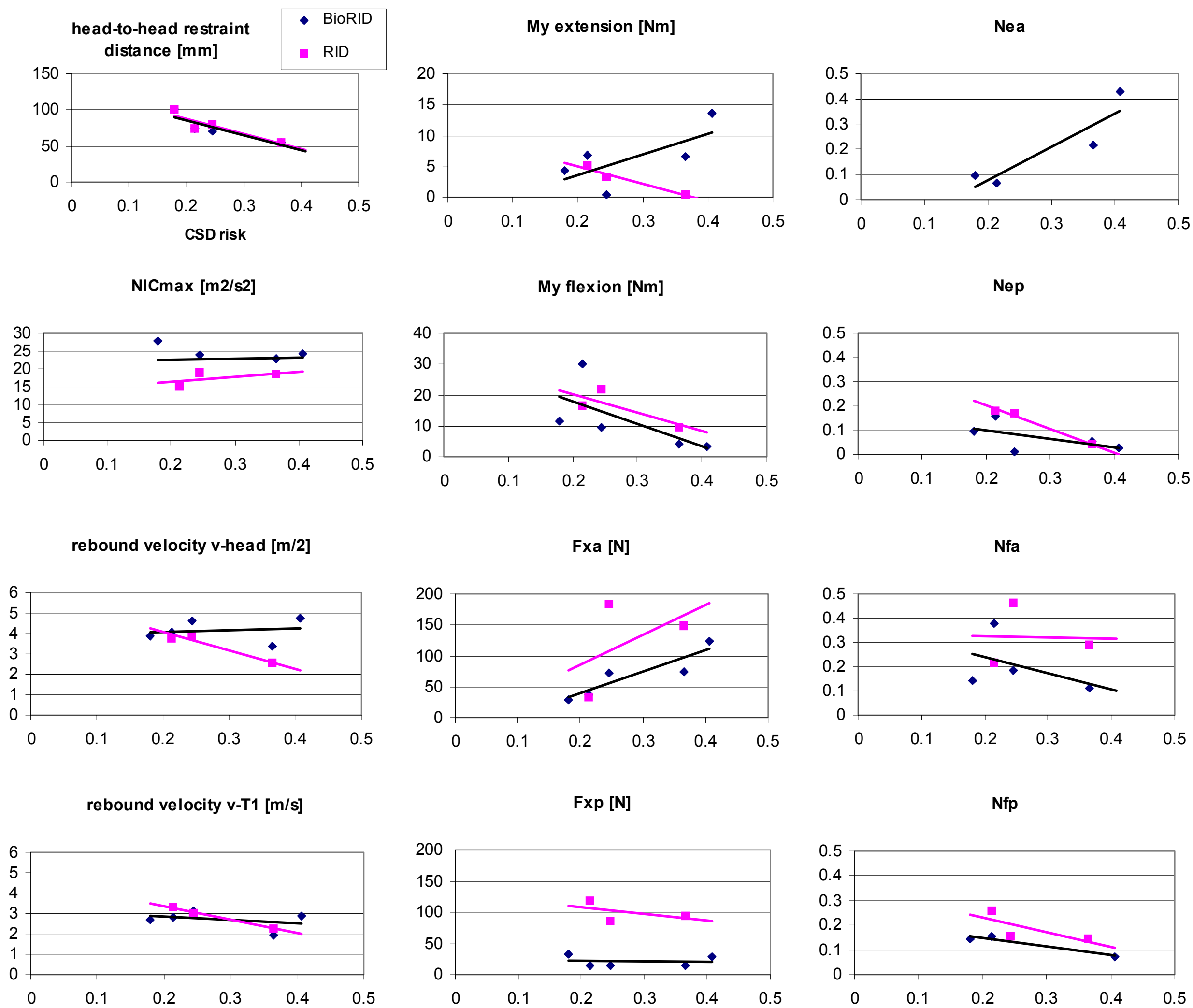
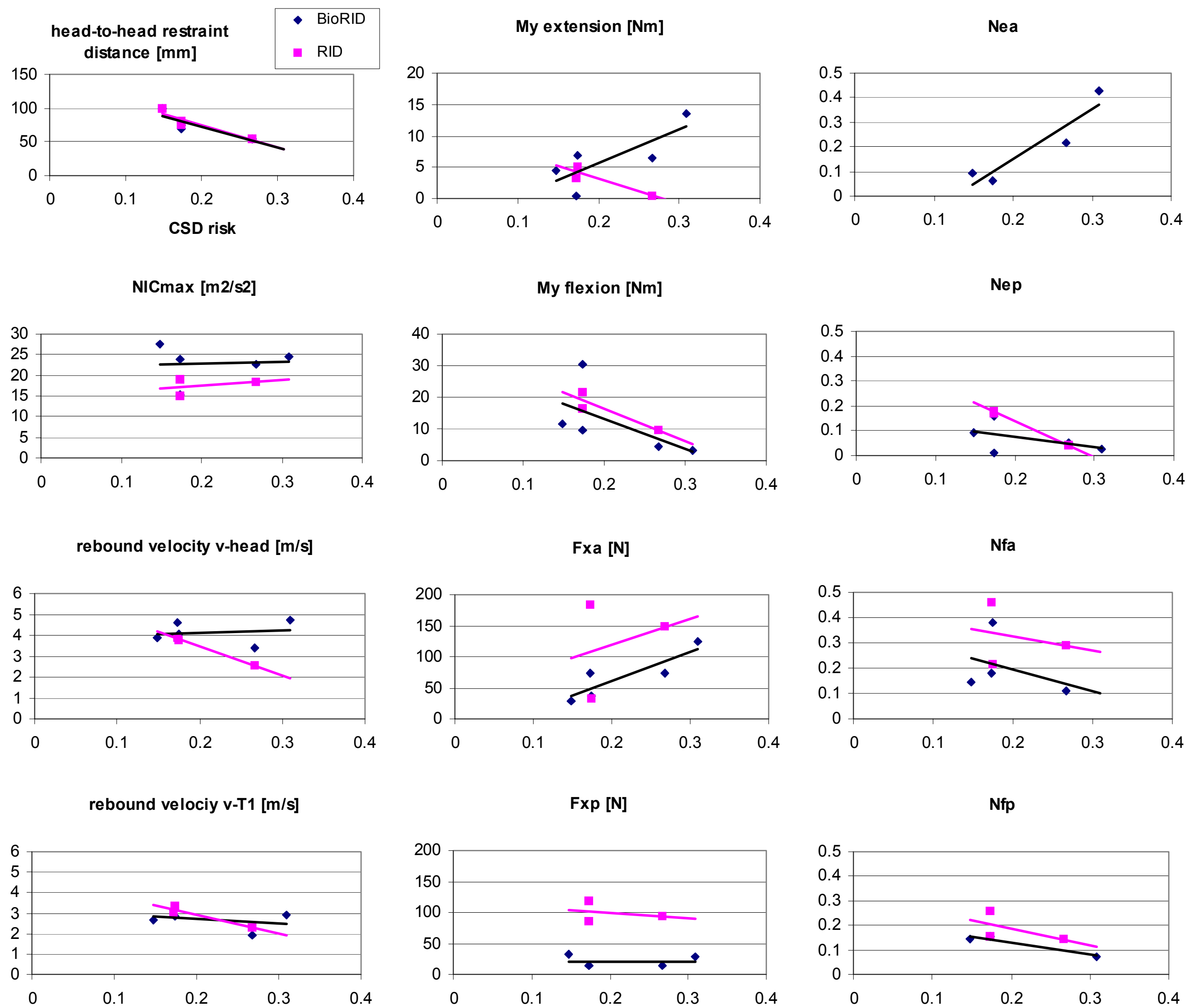
APPENDIX

A) Correlation for all seats and all CSD claims. X-axis represents the injury risk, Y-axis the according parameter. Results for BioRID dummies are plotted in blue, those for RID 2 dummies in purple.



B) Correlation for all seats and for CSD claims up to 6 weeks duration. X-axis represents the injury risk, Y-axis the according parameter. Results for BioRID dummies are plotted in blue, those for RID 2 dummies in purple.



C) Correlation for all seats and CSD claims that lasted more than 6 weeks. X-axis represents the injury risk, Y-axis the according parameter. Results for BioRID dummies are plotted in blue, those for RID 2 dummies in purple.